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MOBILE, ELECTRIC-POWER SOURCE REQUIREMENTS STUDY

Robert R. Wallace, et al

Army Mobility Equipment Research and Development Center
Fort Belvoir, Virginia

October 1972

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MOBILE, ELECTRIC-POWER SOURCE REQUIREMENTS STUDY

by

R. R. Wallace
R. Felts

October 1972

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U. S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT CENTER
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13. ABSTRACT

This study addresses the problem of identifying future requirements for mobile electric power sources, establishing measures of effectiveness for evaluating design goal attainment, and evaluating alternative approaches for attaining the requirements objectives. The study is based upon judgment and logic with some numerical data and analysis.

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October 1972

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SUMMARY

This study addresses the problem of identifying future requirements for mobile, electric-power sources, establishing measures of effectiveness for evaluating design goal attainment, and evaluating alternative approaches for attaining the requirements objectives. The study is based upon judgment and logic with a bare minimum of numerical data and analysis.

FOREWORD

This study was prepared for Mr. John Orth, Chief, Electrotechnology Department, USAMERDC. Effort was started in August 1971; and the report written in December 1971.

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MOBILE, ELECTRIC-POWER SOURCE REQUIREMENTS STUDY

I. INTRODUCTION

1. **Subject.** This study develops a basis for the identification of future requirements for mobile, electric-power sources, establishes measures of effectiveness for evaluating design goal attainment, and identifies and evaluates alternative approaches for attaining the requirements objectives.

2. **Background.** During the past 6 years, many studies have been conducted on the subject of mobile electric power plants.[1-5] In the aggregate, the general objectives of these studies have been:

a. Determine future Army missions.
b. Determine corresponding future materiel requirements.
c. Identify the plausible alternative approaches.
d. Evaluate these alternative approaches and select the "best" or preferred course of action.

These studies have not been able to establish an incontrovertible rationale for the selection of either type or size distribution of future mobile, electric-power plants. Accordingly, the development activities have been proceeding mainly on a basis of intuitive judgment but without functional Materiel Need documentation or visible rationale track back to the threat.

II. INVESTIGATION

3. **Approach to the Problem.** The fact that earlier studies have not been able to establish the necessary guidelines for the development of future mobile, electric-power sources is a measure of the difficulty of the problem. This difficulty stems partly from the complexity of a real-world assessment of power

[1] "Electrical Power Requirements for the Army," USACDC (December 1965).

[2] "Study of 10, 60, and 200 KW Mobile Electric Power for Army Use in the 1975-1985 Time Frame," Army Materiel Systems Analysis Agency, Technical Memorandum No. 76 (August 1970).

[3] "The DOD Standard Family of Gas Turbine Engine Driven Mobile Electric Power Generating Sources – A Life Cycle Cost Study," DOD Project Manager-Mobile Electric Power (1970).

[4] "Supplemental Study to Gas Turbine Engine Driven Generator Set," Ad Hoc Study, AMCPM–MEP–TM (30 June 1970).

[5] "A Materiel Selection Process for Choosing Preferred Small Electric Power Sources," Research Analysis Corporation Study 010.314 (15 April 1971).

consumption in the present Army and partly from the need to establish a reasonably rational basis for extrapolation to future requirements. Also, when future requirements are obtained by extrapolation, there is a strong tendency to extrapolate in a linear fashion. Yet, a "linear" war will not necessarily provide the worst, or most demanding, case that is essential to an identification of the options. There is some evidence that the "today" system is not entirely responsive to current system needs. Any projection from this base into future requirements can then be misleading and deceptive. The issue is further complicated by the existence of a Qualitative Materiel Requirement (QMR) which is directed to a family of military-design electric power plants.[6] In the broadest possible sense, the requirements for power sources should be dictated strongly by the characteristics of the equipment that is to be powered. Power generation should not be regarded as an end objective in itself but only as a subsystem in the system which is made up of power-supply subsystem plus power-consuming-unit subsystem. In this respect, the QMR for power sources is misleading. It diverts attention away from the need for source requirements based upon power-using-equipment needs and regards power generation as an end in itself. By way of comparison, there is a strong tendency to focus too much attention on a ¼-inch drill when what we really want is a ¼-inch hole. A closed-loop requirements review cycle is needed in which power-consuming-equipment characteristics are constantly matched with power-generation-equipment characteristics to be equally aggressive for total system improvement. This point will be examined again later in this study.

Cost of ownership is an important criterion to be considered in determining a course of future action. Not only dollars but other resources such as time, manpower, and materiel also must be considered; and the relative importance of these resources in peacetime and wartime must be brought into perspective. The materiel of today is cost effective only with the threats and requirements of today. Then, in the final decision-making process, there must be access to two distinct inputs: cost (resources), and effectiveness.

This study is concerned primarily with effectiveness and will attack the problem of future requirements and measures of effectiveness.

The need for an abbreviated attack upon the problem is based upon the belief that depth of detail and massive data can easily blur or even totally obscure key facts and faulty assumptions. In this short approach to an outcomes matrix, emphasis is placed upon simplifying and reducing real-world complexities.

[6] "Revised DA Approved Qualitative Materiel Requirement for a Family of Military Design Electric Power Plants," USACDC (8 June 1971).

Simple models will be postulated and exercised in a set of conditions designed to range from "best" case to "worst" case.

This part of the study begins with a postulation of a mission profile for the U.S. Army over the next 10 years. The profile has been selected to provide a "worst" and "best"* base for the derivation of the following function requirements:

a. Assistance to Civil Authorities.
b. Materiel Aid to second and third countries.
c. Direct Involvement in conflict.
   (1) Fluid Theatre, short duration (30-60-90 days).
      (a) Combat Zone
      (b) Communications Zone (Comm Z).
   (2) Mature Theatre, longer duration (over 90 days).
      (a) Combat Zone
      (b) Comm Z.

a. Assistance to Civil Authorities. Assistance to Civil Authorities is intended to encompass civil disorder control, civil defense, civil engineering, and natural disaster relief. In each of these instances, the function requirements for electric power generation are regarded as technically undemanding. Resources of manpower, time, and modes of transport are relatively abundant, duty cycles are short, stockpiles of equipment are close at hand, and redundancy does not carry a heavy cost or effectiveness penalty.

b. Materiel Aid. Materiel Aid is intended to reflect high-level policy guidance which seeks a low profile in international affairs and military presence. U.S. Army involvement in counter insurgency and wars of liberation is thus assumed to be limited to materiel support only. Here, again, the function requirements for electric power generation are technically undemanding. Resources of manpower and time are assumed to be relatively abundant but modes of field transport, handling, maintenance facilities, and training are assumed to be marginal if not primitive. Duty cycles and time between overhauls might be longer than above but ample spares would be readily available. Due to the probable need to interface with a broad variety of indigenous supply systems and non U.S. materiel, multi-frequency capability is required and multifuel operability is nice to have.

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* "Worst" case is defined as conditions most demanding upon the current system; while "best" case is the least demanding, i.e., favorable.

c. **Direct Involvement.** In the area of Direct Involvement, the mature theatre, longer-duration conflict has been selected as an extension of "linear" warfare. This implies that the future scenario is a direct extrapolation from today with only slight evolutionary changes in materiel and tactics.

The following assumptions for a mature theatre are postulated:

(1) Duration 90 days plus.
(2) Forces operate as units.
(3) Normal troop dispersion.
(4) Renewal of equipment and supplies from time to time.
(5) Combat forces mobile; rear echelon semi-mobile to mobile.
(6) Distinction between Comm Z and Combat Zone.
(7) Limited maintenance.
(8) Limited repair facilities.
(9) Some electrical power used for housekeeping and creature comforts.
(10) Little mismatch between electrical-using and electrical-generating equipment.
(11) Operating personnel generally qualified.
(12) Some equipment that is not highly mobile and/or vital to survival will be destroyed/abandoned.

A fluid theatre, short-duration conflict has been selected to provide the greater challenge to materiel in the current inventory. Here, the floating island force concept is involved with the following assumptions:

(1) Duration 30-60-90 days.
(2) Forces are broken down to very small units.
(3) Forces are widely scattered.
(4) Little or no renewal of equipment or supplies.
(5) Forces are highly mobile.
(6) Little or no distinction between Combat Zone and Comm Z.
(7) Practically no maintenance.
(8) No repair facilities.
(9) No electrical power used for housekeeping or environmental control for personnel.
(10) Some mismatch between electrical-using and electrical-generating equipment.
(11) Unqualified operating personnel in many instances.
(12) Adequate supply of fuel for mobility vehicles available in both zones.

The two theatres are compared in Table I.

Table I. Comparison of Fluid Theatre and Mature Theatre

	Item	Fluid	Mature
1.	Duration	30-60-90 Days	Over 90 Days
2.	Unit Sizes	Very Small	Standard
3.	Dispersion	Widely Scattered	Standard
4.	Materiel Resupply	Very Little	Standard
5.	Organization Disposition	Little Physical Distinction between Comm Z and Combat Zone	Clear Physical Distinction Between Comm Z and Combat Zone
6.	Mobility	Very High Mobility	Comm Z: Semi-mobile Combat Zone: Mobile
7.	Maintenance	Limited to None	Standard
8.	Repair Facilities	None	Standard
9.	Electrical Consumption for Housekeeping and Personnel Environmental Control	None	Some
10.	Operating Personnel	Unqualified in Many Instances	Qualified
11.	Equipment Match	Generally Poor Match between Power Sources and Power Consumers	Good Match Between Power Sources and Power Consumers
12.	von Clausewitz Difficulty Factor	Very High	High

4. **Measures of Effectiveness.** At this point, the measures of effectiveness that will be used for evaluation of alternatives must be defined. Effectiveness is defined as a measure of the extent to which a system may be expected to achieve a set of specific mission requirements.[7] It is a function of the system's availability,

[7] AMCR 706-191.

dependability, and capability. The basic approach for evaluating the effectiveness of a system can be empirical or analytical.

Availability, dependability, and capability are separate components that are linked by conditional probability. This condition requires that additional measures are significant if and only if previous measures have been fulfilled.

a. **Availability.** Availability is defined as a measure of system condition at the start of the mission.[8] It normally includes such terms as time between maintenance actions and repair time.

b. **Dependability.** Dependability is defined as a measure of the system condition at one or more points during the mission given the system condition at the start of the mission. It includes terms normally associated with reliability and maintainability.[9]

c. **Capability.** Capability is defined as a measure of the system ability to achieve the mission objectives given the system condition during the mission. Capability specifically accounts for the performance spectrum of the system.[10]

5. **The Requirements for Mobile Electric Power Sources.** With the mission profiles postulated and effectiveness and its components defined, the next task is to identify, define, and discuss requirements in a context of effectiveness. The following relationships to effectiveness are postulated:

Availability
- Multifuel Operability
- Scheduled Maintenance
- Check Out Time
- Trouble Shooting
- Repair Time
- Time between Maintenance

Dependability
- Reliability
- Environmental Adaptability
- Maintainability
- Failure Rates
- Degrade Modes
- Back-up Modes
- Time Between Overhauls

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[8] AMCR 706-191.
[9] Ibid.
[10] Ibid.

Capability

Linking

Multifrequency

Emissions

Specific Fuel Consumption (SFC)

Power Output

Endurance Life

Reaction Time

This is indeed a formidable list of requirements to evaluate individually and then collectively without some guidelines for relative importance. A clue to relative importance may lie with the five traditional functions of land combat, i.e.:

(1) Intelligence/Reconnaissance/Security
(2) Firepower
(3) Mobility
(4) Command/Control/Communications
(5) Combat Services Support

a. Mobility. The overlap between mobility and the other functions has been difficult to resolve in this study. Also, in earlier studies on other unrelated system problems, the somewhat ambiguous nature of the combat functions has been troublesome. In an attempt to correct this problem and to build an analytical model that incorporates the functions of land combat, this study is proposing that the accepted definition of effectiveness be modified to include a mobility term (Table II). Using the accepted definition of effectiveness as a conditional probability and then including mobility as one of the availability terms results in four functions of land combat, i.e.:

(1) Intelligence/Reconnaissance/Security
(2) Firepower
(3) Command/Control/Communications
(4) Combat Services Support

and Mobility is an Effectiveness term common to each.

Table II. Modified Term for Availability

System Effectiveness = Availability X Dependability X Capability

AVAILABILITY =	INITIAL DEPLOYMENT MOBILITY + FIELD MOBILITY + ON-SITE TERMS MULTIFUEL SCHEDULED MAINTENANCE CHECK-OUT TIME TROUBLE SHOOTING REPAIR TIME TIME BETWEEN MAINTENANCE ACTIONS

Availability may then be regarded as having two principal terms:

(1) Mobility
  (a) Initial deployment mobility
  (b) Field mobility
(2) On-site terms which consist of the traditional statistical considerations describing the equipment after it is initially deployed.

This point is illustrated in Table III.

By this logic, mobility assumes a position of high relative importance as a requirement. AR 320-5 defines mobility as "A quantity or capability of military forces which permits them to move from place to place while retaining the ability to fulfill their primary mission." The key elements in military mobility are movement and mission. Movement can consist of moving or being moved and involves a change in space-time coordinates. Although AR 320-5 uses the expression ". . . . .while retaining the ability to fulfill their primary mission," an important aspect of improvement in mobility is the increased ability to fulfill secondary missions if the primary mission is aborted.

Mobility must include not only the basic item or items but also all related items. For example: If the mobility of a field generator is under consideration, all fuel, spare parts, tools, environmental aids, etc. should be included in the study. In addition, handling characteristics such as size, shape, and weight in particular can strongly influence the degree of mobility achieved. The relationship of the

Table III. Systems Measures of Effectiveness

LAND COMBAT SYSTEM EFFECTIVENESS =

1.	$\text{AVAILABILITY}_{\text{INTEL.}}$	×	$\text{DEPENDABILITY}_{\text{INTEL.}}$	×	$\text{CAPABILITY}_{\text{INTEL.}}$
2.	$\text{AVAILABILITY}_{\text{FIREPOWER}}$	×	$\text{DEPENDABILITY}_{\text{FIREPOWER}}$	×	$\text{CAPABILITY}_{\text{FIREPOWER}}$
3.	$\text{AVAILABILITY}_{\text{COMMAND/CONTR.}}$	×	$\text{DEPENDABILITY}_{\text{COMMAND/CONTR.}}$	×	$\text{CAPABILITY}_{\text{COMMAND/CONTR.}}$
4.	$\text{AVAILABILITY}_{\text{CSS}}$	×	$\text{DEPENDABILITY}_{\text{CSS}}$	×	$\text{CAPABILITY}_{\text{CSS}}$

EACH AVAILABILITY TERM INCLUDES

INITIAL DEPLOYMENT MOBILITY
+
FIELD MOBILITY
+
ON-SITE TERMS

condition of mobile equipment at the start of the mission to the condition of the equipment during and after the mission relates directly to availability, dependability, and capability. By the same logic, the degree of mobility of any item is dependent upon the situation under consideration. A truck might, in relation to infantry, be assumed to be quite mobile; while, in relation to fighter aircraft, the truck would be almost immobile. A heavy generator set might be relatively mobile in a mature theatre and highly lacking in mobility in a fluid theatre.

Other important parameters of mobility are geographic, climatic, economic, and political considerations. Also of interest is the relative degree of mobility on land, at sea, or in the air, and various combinations of these.

Any separate but related activities which allow increased mobility or which restrain mobility must be considered as elements of mobility. As examples, tanker aircraft allow increased mobility of fighters, bombers, and transports. Almost any construction activity increases mobility of personnel and equipment while mine fields, booby traps, and other barriers decrease mobility of opposing forces.

Mobility, then, is a system (or systems) of non-fixed personnel and equipment which can to varying degrees change or have changed their space-time coordinates in order to accomplish a mission or missions in given situations while operating under various constraints. Conversely, a modification of degree of movement and/or mission is achieved by a change in constraint.

In this study, it is believed necessary to make a distinction between types of mobility.

b. Initial Deployment Mobility and Field Mobility. Initial deployment mobility will be considered to mean mobility within CONUS and from CONUS to OCONUS, i.e., from manufacturer to an OCONUS Army Depot. Field mobility will be from the OCONUS Depot to the using field forces and then to destruction or return to Depot.

In both types of mobility, the elements are: Planning and scheduling, time, modes of transportation, handling equipment, and manpower.

(1) Initial Deployment Mobility. There is, in general, sufficient lead time in this case to allow adequate planning and scheduling of shipments. Time, while important, is seldom critical. A wide variety of handling equipment is usually available; and, if nonstandard equipment is required, it is designed and built to cover the situation. Manpower is, in most cases, abundant and working

on a full-time, primary duty basis. This includes both military and civilian personnel. The modes of transportation include land, sea, and air, both military and civilian, and are usually conventional in nature. Land transportation will generally consist of rail and/or truck where the trucking takes place on road or highways. Sea transportation consists primarily of military or civilian cargo ships. Air cargo planes are employed for the air mode. In all of the above methods, the transportation equipment has been developed, modified, and improved over the years to move all reasonable weights, sizes, and shapes of equipment over established routes under standard operating procedures.

(2) **Field Mobility.** Although some generalized planning and scheduling is done in anticipation of various situations, there is little or no lead time during emergencies. Time is so vital that it is often bought with men's lives. Field forces during an intense, possibly short duration, war would not be expected to have much, if any, handling equipment except of the most basic and primitive nature. Manpower is concerned with many objectives, and moving equipment from place to place is a means to these ends, not an objective in itself. The transportation modes are still land, sea, and air but will vary from quite sophisticated to extremely primitive. Land transportation may vary from rail and/or trucks on a road to animal powered transportation to human power. The surfaces traversed may range from good roads to cross-country in swamp, desert, or mountains. Sea or water transportation may still be by cargo ship but more likely will consist of lighter landing craft or small nonmilitary boats. Air cargo planes will be used as well as helicopters and small planes. In many phases of field mobility, the available transportation modes will be makeshift and/or inadequate with the result that any equipment that is too heavy, too large, or too awkward to fit the transportation will not be available for use.

Summarizing, this study postulates that mobility is a critical term of availability and that weight is very nearly synonymous with mobility.

The additional terms presented earlier under availability, dependability, and capability are defined in the Appendix.

c. **Mission/Effectiveness Requirements.** The requirements are then arranged against the postulated mission profiles and their relative importance is estimated on a scale from 0 to 3 in a mission/effectiveness requirements matrix (Table IV). Several tentative conclusions may be drawn from this matrix:

(1) Assistance to Civil Authorities and Materiel Aid are relatively undemanding in terms of availability, dependability, or capability. This arises from

Table IV. Measures of Effectiveness for Mobile Electric Power Sources
Rated from 0–3 in Relative Importance

Measures of Effectiveness	MISSION PROFILE					
	Assistance to Civil Authorities	Materiel Aid	Direct Involvement			
			Fluid Theatre		Mature Theatre	
			Combat Zone	Comm Z	Combat Zone	Comm Z
Availability						
Initial Deploy, Mobility	1	1	3	3	3	2
Field Mobility	1	2	3	3	3	2
Multifuel	1	2	3	3	3	2
Scheduled Maintenance	1	2	2	2	2	2
Check-out Time	1	2	2	2	2	2
Trouble Shooting	1	2	2	2	2	2
Repair Time	1	2	2	2	2	2
Time Between Maint. Actions	1	2	2	2	2	2
Dependability						
Reliability	1	2	2	2	2	2
Environmental Adaptability	1	2	2	2	2	2
Maintainability	1	2	2	2	2	2
Failure Rates	1	2	2	2	2	2
Degradation Modes	1	2	2	2	2	2
Back-up Modes	1	2	2	2	2	2
Time Between Overhauls	1	2	2	2	2	2
Capability						
Linking	1	2	2	2	2	2
Multi Frequency	1	2	2	2	2	2
Emissions	1	1	2	2	2	2
Specific Fuel Consumption	1	1	2	2	2	2
Power Output	1	2	2	2	2	2
Endurance Life	1	2	2	2	2	2
Reaction Time	1	2	2	2	2	2

the relative abundance of modes of transport, manpower, fuels, spares, and time, to name a few. Also, vital interests are certainly involved in these missions but the outcome of any single event is not critical in the broad military sense.

(2) Availability, dependability, and capability requirements are higher in the Direct Involvement missions; and the matrix shows that the availability term has the most demanding requirements. This stems from the need for initial deployment mobility and field mobility in combat zones. Probably the most significant feature of this matrix is the midpoint rating of 2 assigned to the dependability terms. The rationale for this rating is that dependability will be attained by TOE redundancy regardless of the inherent statistical dependability of the type-classified power source.[11] "Up" time is thus confidently attained via spares.

A similar rationale of TOE redundancy is also used to rate the relative importance of capability at a midpoint value.

The matrix appears to indicate that, from the effectiveness standpoint, the mission profile encompasses two separate and distinct missions, i.e.

Combat

Noncombat.

Then, it follows that a design that meets, for example, a high field mobility requirement would be over-designed if not unresponsive in a noncombat mission. The designer has the following three choices in a dilemma of this type where requirements are conflicting if not mutually exclusive:

(1) Single Design. Pick a midpoint and compromise the most-demanding with the least-demanding requirements.

(2) Single Design. Design to satisy the most-demanding wartime requirements and accept the penalties of peacetime over design.

(3) Make two designs.

But decisions are not based upon effectiveness considerations alone. Resources must also be considered and the value of these resources appraised. In Table V,

[11] "Study of 10, 60, and 200 KW Mobile Electric Power for Army Use in the 1975-1985 Time Frame," Army Materiel Systems Analysis Agency, Technical Memorandum No. 76 (August 1970).

Table V. The Value of Resources in Relation to Specific Mission
(Rated from 0–3 in Relative Importance)

Mission	Men (Peace Time)	Men (War Time)	Time (Peace Time)	Time (War Time)	Materiel (Peace Time)	Materiel (War Time)	Dollars (Peace Time)	Dollars (War Time)
1. Assistance to Civil Authorities	1	1	1	1	1	1	3	3
2. Materiel Aid	0	1	1	2	1	2	3	2
3. Direct Involvement Fluid Theatre with Short Duration								
a. Combat Zone	NA	3	NA	3	NA	3	NA	0
b. Comm Z	NA	3	NA	2	NA	3	NA	0
4. Direct Involvement Mature Theatre with Longer Duration								
a. Combat Zone	NA	3	NA	3	NA	3	NA	0
b. Comm Z	NA	2	NA	2	NA	2	NA	1

PEACE TIME	WAR TIME

the mission profile is arrayed against resources of men, time, materiel, and life-cycle dollar cost. This matrix presents an estimation of the relative value of these resources to specific missions under wartime and peacetime conditions. In a manner similar to Table IV, a scale of 0 to 3 has been used to estimate relative value of resource. Here, again, an inverse relationship of resource value shows up when the mission profiles are matched to wartime and peacetime. For Assistance to Civil Authorities and Materiel Aid, men, time, and materiel are relatively abundant in wartime or peacetime while dollar cost is relatively critical in either case. Direct Involvement is another matter entirely; for, in this case, men, time and materiel aid are relatively scarce and dollar cost is secondary. Then, from the individual appraisals of effectiveness criteria and resource criteria that have just been presented, it appears that the problem of mobile electric power sources may not be amenable to a single solution. What are the options?

Assume for the moment that the selection is limited to diesel-type power and/or turbine-type power. Table VI presents the relative cost and effectiveness of each power-source type in a matrix of wartime and peacetime for three periods of time; 1970, 1980, and 1990. Under Period 1 of Table VI, the 1970 period, the peacetime life cycle cost data from the PM-MEP DOD source is presented.[12] Considering the uncertainty of these estimates, the relative cost of diesel and turbine power is already nearly equivalent for equivalent peacetime effectiveness. Wartime costs are presented as not applicable for reasons previously stated (Table V). The relative wartime effectiveness of the turbine is presented as about 4 times higher than the diesel, even at the present state of development, due to the weight factor.

Period 2 of Table VI is the 1980 period. The options are presented as equivalent in both cost and effectiveness for peacetime. For wartime, however, the turbine is believed to have the greatest potential for mobility design improvement while the diesel is well into diminishing returns on product improvement investment.[13] The steady improvement in cost, reliability, and performance of the aircraft turbine is an outstanding example of product improvement.

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[12] "Supplemental Study to Gas Turbine Engine Driven Generator Set," Ad Hoc Study, AMCPM-MEP-TM (30 June 1970).

[13] "Study of 10, 60, and 200 KW Mobile Electric Power for Army Use in the 1975-1985 Time Frame," Army Materiel Systems Analysis Agency, Technical Memorandum No. 76 (August 1970).

Table VI. Relative Cost and Effectiveness

Periods of Time Power Source	Peace Time Life Cycle Cost - $ (a)	Peace Time Effectiveness	War Time Life Cycle Cost - $	War Time Effectiveness (b)
PERIOD 1: 1970 ALL DIESEL DIESEL AND TURBINE ALL TURBINE	162,000 ≅ 1.00 HIGHEST 189,000 ≅ 1.16	EQUIVALENT	NOT APPLICABLE	LOWEST ≅ 0.25 MIDPOINT HIGHEST ≅ 1.00
PERIOD 2: 1980 ALL DIESEL DIESEL AND TURBINE ALL TURBINE	EQUIVALENT	EQUIVALENT	NOT APPLICABLE	LOWEST POTENTIAL HIGHEST POTENTIAL
PERIOD 3: 1990 ALL TURBINE TURBINE AND OTHER ALL "OTHER"	LOWEST HIGHEST MIDPOINT	EQUIVALENT	NOT APPLICABLE	LOWEST HIGHEST

(a) "Supplemental Study to Gas Turbine Engine-Driven Generator Set," Ad Hoc Study, AMCPM-MEP-TM (30 June 1970)

(b) EFFECTIVENESS ≅ MOBILITY ≅ 1/WEIGHT.

Period 3 of Table VI is the 1990 period and beyond. The main thrust of these relationships is that evolutionary change is inevitable. Just as the diesel will be displaced in many situations by the turbine, so the turbine will be displaced by something else. As in the first two periods, peacetime effectiveness is presented as equivalent because peacetime effectiveness is not really the primary design goal. Progress in the technology of power-using equipment and power-generating equipment must force a continuing appraisal of future missions and requirements. The most cost-effective solution for today will not be valid tomorrow.

III. DISCUSSION

6. **Mobility and Effectiveness.** The PM-MEP DOD source states that "... .turbine generator sets will be required wherever overriding requirements for mobility are of primary concern. . . ."[14] If it is accepted that mobility is a critical requirement for availability and that availability is the first term of the availability x dependability x capability product term that makes up effectiveness, then mobility is indeed an overriding requirement for effectiveness. There is no point in examining the fine-line spectra of dependability and capability if the equipment is not available where needed and then when needed in combat.

7. **Effectiveness and Cost.** If it is granted that the turbine is inherently more mobile than the diesel in either initial deployment or field maneuver, then it follows that the turbine will have the highest wartime effectiveness. That is what it is all about. The fact that current turbines may have a slightly higher peacetime life-cycle cost at present is not the most significant issue. Peactime effectiveness and wartime effectiveness must be measured with two different yardsticks. This point cannot be overemphasized. Any attempt to design a single family of power sources to meet the most demanding wartime military needs will certainly not be resource effective in meeting peacetime military needs. Conversely, equipment that will satisfy peacetime effectiveness and cost requirements will be inadequate for wartime missions where dollar cost is incidental to effectiveness.

8. **The Single-Family Concept.** There is, in fact, no such thing as a single family of equipment in the inventory at any point in time. There will almost always be one family of newer equipment that is emerging while another

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[14] "Supplemental Study to Gas Turbine Engine Driven Generator Set," Ad Hoc Study, AMCPM-MEP-TM (30 June 1970).

family of older equipment is approaching the disposal phase. Thus, a plateau of transition bridges the gap between an inventory that is 100% old and 100% new. With older equipment, the best that we can hope for is mobility parity, but the name of the game is not mobility parity but mobility superiority. Then, the problem is not so much the desirability of turbines, per se, but rather the consequences of not having a high-mobility turbine supply when mobility is essential.

9. **Sizes.** The sizes of mobile electric power sources that may be required for the future Army can be determined by examining the materiel to be operational at any point in time. It appears, however, that the fluid theatre, floating island force will put a premium upon power sources that are as mobile as small groups of men can be made to be. Assuming that this mobility is achieved by small ground vehicles and helicopters, then the vehicle characteristics will dictate some of the mobile electric power source requirements. For the transition period of the next 5 years or so, some efforts should be placed upon the smaller, high-mobility sizes. They can be grouped for a large power requirement; but a single larger, lower-mobility single unit cannot be broken down into smaller, high-mobility packages.

10. **Cost.** Most studies conducted to date show a strong preoccupation with the criterion of cost while effectiveness has not been addressed in specific terms. Literally, nothing is acquired on cost considerations alone!

IV. CONCLUSIONS

11. **Conclusions.** The present study is directed to the broadest possible questions associated with diesel electric power generation and turbine electric power generation. It does not attempt to either optimize or deal with technical detail because such treatment is not appropriate for development problems and can easily lead to premature suboptimization.

Finally, it is generally agreed that decisions are most often made in a management environment of requirements and constraints totally unlike the environment of the systems analyst. This is not meant to imply that the analyst does not also make decisions. Actually, he is the first who must choose from a bewildering array of options and data points if the study is to proceed at all. The best that can be expected from analysis, however, is some clarification of issues and a perspective upon the alternatives.

With these caveats the following conclusions are offered:

a. The prime mission of the Army is to acquire and maintain combat effectiveness.

b. Effectiveness is defined as a conditional probability composed of availability, dependability, and capability.

c. Availability, as the first term of effectiveness, is composed of initial deployment mobility, field mobility, and on-site availability terms.

d. Mobility is constrained or defined primarily in terms of weight.

e. In combat, equipment that is lightweight (i.e., mobile) has the highest probability of being available when and where needed.

f. The gas turbine has, and will continue to show, a distinct weight (i.e., mobility) advantage over diesel engines for mobile electric power plants.

g. Although there is little if any significant difference in life-cycle costs between gas turbines and diesel engines at present,[15] experience with aviation turbines indicates that turbines have a clearly superior potential for cost reduction and effectiveness improvement.

h. The development of gas turbine mobile electric power sources should proceed to insure an improved combat mobility capability. The consequences of *not* having high mobility electric power sources are grim.

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15 "Supplemental Study to Gas Turbine Engine Driven Generator Set," Ad Hoc Study, AMCPM-MEP-TM (30 June 1970).

APPENDIX

DEFINITION OF TERMS

1. Multifuel
2. Scheduled Maintenance
3. Check Out Time
4. Trouble Shooting
5. Repair Time
6. Time Between Maintenance Action
7. Reliability
8. Environmental Adaptability
9. Maintainability
10. Failure Rates
11. Degrade Modes
12. Back-up Modes
13. Time between Overhauls
14. Linking
15. Multifrequency
16. Emissions
17. Specific Fuel Consumption
18. Power Output
19. Endurance Life
20. Reaction Time

1. Multifuel

Multifuel is defined as the capability to operate on a variety of fuel types with no significant short-term impairment of power generating capability. Details are given in DOD Directive 4120.12 "Fuels Policy. . . . "

2. Scheduled Maintenance

Scheduled maintenance is defined as all actions necessary for retaining an item in or restoring it to a specified condition.* Preventive maintenance is defined as actions performed in an attempt to retain an item in a specified condition by providing systematic inspection, detection and prevention of incipient failure.* Scheduled maintenance is used in this study to denote maintenance that is performed at established intervals of time. Examples would include oil changes, fan belt replacement, and similar actions on an established statistical basis.

*MIL-STD-721B.

3. Check Out Time

Check Out Time is defined as the time required for tests or observations that are necessary to determine the condition or status of an item.*

4. Trouble Shooting (Fault Location Time)

Trouble Shooting is defined as that element of maintenance time during which testing and analysis are performed on an item to isolate a failure.*

5. Repair Time (Corrective Maintenance Time)

Repair Time is defined as the time required to accomplish the actions that are necessary to restore an item to a specified condition after failure.*

6. (Mean) Time between Maintenance Action

(Mean) Time between Maintenance Action is defined as the mean of the distribution of the time intervals between maintenance actions (either preventive, corrective, or both).*

7. Reliability

Reliability is defined as the probability that an item will perform its intended function for a specified interval under stated conditions.*

8. Environmental Adaptability

As used in this study, Environmental Adaptability refers to a capability to perform the intended mission with low retrofit or modification time for a specific geographic, climatic, or meteorological condition.

9. Maintainability

Maintainability is defined as a characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time when the maintenance is performed in accordance with prescribed procedures and resources.*

10. Mean Time between Failures (MTBF)

MTBF is defined as the total functioning life of a population of an item divided by the total number of failures within the population during the measurement interval.*

11. Degradation Modes

As used in this study, Degradation Modes refers to the routes by which any of the system elements (i.e., hardware, facilities, personnel, procedural data) can fail.

*MIL-STD-721B.

12. Back-up Modes

As used in this study, Back-up Modes refers to redundancy in any or all of the systems or system elements.

13. Time between Overhauls (TBO)

In this study, TBO refers to major scheduled maintenance.

14. Linking

The capability of power generators to operate in parallel electrical connection with other sizes and types of power sources has an important impact on power rating requirements. Where linking is feasible, great flexibility of power systems is possible.

15. Multi-Frequency

Multi-Frequency refers to the capability of any single power generator to provide 50 to 60 and 400 Hz by simple selection or adjustment. An alternate approach would be to employ separate power sources for different frequencies.

16. Emission

Emission is associated with the generation and dissemination of electromagnetic, acoustic, chemical, and other signals that may be detected and utilized by the enemy for countermeasures. For special conditions that require extremely low emission, all standard power generators, regardless of type, will probably be inadequate; and special units, designed for specific missions, will be required. Standard types of generators will be evaluated on relative emission.

17. Specific Fuel Consumption (SCF)

SFC is defined as pounds of fuel consumed per kilowatt hour produced. If the required fuel is not common to vehicles or other high fuel consuming equipment, logistics and costs may be relatively important. When a fuel common to vehicles can be used, the delta imposed on existing logistics and costs will generally be insignificant for any reasonable SFC.

18. Power Output

Power Output, as a capability factor, should be considered from the viewpoint of kilowatt hour produced per pound of generator weight. The interaction of fuel consumption and power output is considered under the heading of specific fuel consumption.

19. Endurance Life

Endurance Life is that period of time between deployment and disposal. It includes storage, stand-by, up time, and down time. Design, environment, maintenance procedure, and usage influence endurance life. In most cases, relative, rather than absolute, endurance life determines the advantage or disadvantage of a system in this term.

20. Reaction Time

Reaction Time includes installation, check-out, start-up, and war-up (when required). The importance of reaction time varies with specific mission requirements which also defines minimum allowable reaction time.